

Report No. RD-66-15

TECHNICAL REPORT

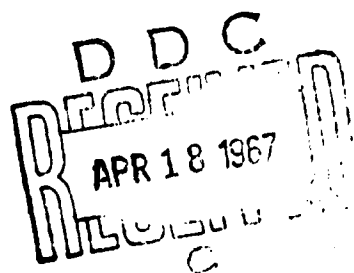
Project No. 320-205-02N

TRAILING CONE TESTS IN LARGE TURBOJET

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FEDERAL AVIATION AGENCY
Systems Research & Development Service
Washington, D.C.

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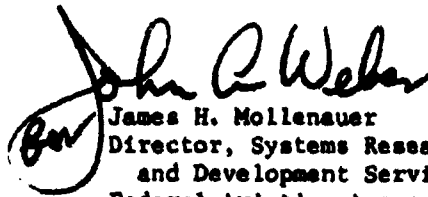
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Prepared by:

William M. Russell

March 1966

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James H. Mollenauer
Director, Systems Research
and Development Service
Federal Aviation Agency

Navigation Development Division
Approach and Landing Branch
Washington, D.C.

ABSTRACT

The report explains FAA tests in a large turbojet airplane of the trailing cone technique for measuring static source error. During the test series a total of nineteen (19) flights were flown investigating the physical and operational parameters affecting trailing cone system performance. Several items pertinent to conducting trailing cone calibrations are also discussed. Recommendations are stated regarding application of the technique to airworthiness determination and establishing eligibility for 1000 foot vertical separation.

INTRODUCTION

Use of the trailing cone system promises to be the breakthrough that will permit economical validation of airplane static systems used for barometric altimetry, providing indication of vertical separation in instrument flight. After initial testing, this new technique was put to use in a limited application on commercial jet airplanes where unexplained performance variations were discovered. Between June and December of 1965, the Federal Aviation Agency conducted a series of flight tests in a C-135 jet airplane to determine the cause of the unknown variations.

BACKGROUND

Pressure altimetry is the international standard for vertical separation of airplanes presumably because it is not affected by variations in ground elevation and because of the availability at reasonable cost. In flight, the atmospheric pressure, which is inversely related to the pressure altitude, must be sampled at the level of an airplane for it to be measured by the altimeter inside the airplane. Difficulty arises as the airplane itself disturbs the pressure of the atmosphere around it, more so at high speeds. The pressure at conventional static ports located on the airplane is susceptible to errors created by this disturbance. To properly correct for these errors, the airplane and its static pressure ports must be calibrated.

Recently, there has been considerable interest in reducing the vertical separation of airplanes in the high altitude airways. Economic considerations dictate that some major advances must be made if the Air Traffic System is to handle the increasing traffic; reducing the vertical separation to 1,000 feet would practically double the capacity. However, safety must not be sacrificed. For validation of the safety required, the standard has been used that the static system error be measured to within ± 50 feet. Conventional calibration techniques properly applied can meet this accuracy requirement up to altitudes of about 45,000 feet, but are too expensive for application to a fleet of high speed jet airplanes. This expense is primarily due to the large amount of flight time required by these methods.

The trailing cone system is a technique of suspending a static port far enough behind an airplane to be relatively unaffected by the aerodynamic disturbances of the airplane. The pressure sampled by the system can then be directly compared to the pressure sampled by the airplane's own system. If the cone system has zero error, the difference between the two pressures

is error of the airplane's static system. If the technique is acceptable, it could be applied as an accuracy check at one altitude with 45 minutes or less flight time, greatly reducing the expense of such a check.

The drag cone itself is only used to hold the static port straight out behind the airplane. The pressure is conducted from a metal sampling tube forward into the airplane through a long plastic tube (usually nylon). The actual drag forces of the cone are usually transmitted to the airframe by a steel cable within the plastic tube. This system had been recommended by early tests as having considerable promise (References 2 and 4). However, these tests were limited to small fighter type jet airplanes. Later operational tests by U.S. air carriers on large jet airplanes revealed differences between the performance of two cone systems behind one airplane equivalent to as much as 50 feet in altitude at 35,000 feet. The cone systems could not both have zero error. A close scrutiny of the two cone devices indicated small differences in physical configuration that were previously thought to be of no consequence.

As test objectives required the total calibration to be accurate to within ± 50 feet, these discrepancies on top of original cone calibration errors created large questions as to the true character of the techniques.

TEST SERIES

The Federal Aviation Agency, with assistance from the National Aeronautics and Space Administration, conducted a test program designed to isolate the critical parameters affecting trailing cone system performance. A large four engine jet transport (C-135) was used as the test vehicle. In addition to the physical parameters noted earlier, the tests included some operational parameters or techniques that might be affecting cone performance. The parameters tested and the variations introduced are indicated in Table I. In order to limit the magnitude of the tests, only as few changes of each parameter as would be significant were included.

TABLE I

Parameter	Values Tested
Drag Cone size	8-inch maximum diameter conical 13-inch maximum diameter flared cone
Metal static tube size	.25 inch diameter .31 inch diameter
Static orifice size	Standard (No. 76 drill) Twice standard
Length of trail behind airplane	170 feet aft of airplane tail cone 100 feet 75 feet 50 feet
Wear by dragging cone during takeoff and landing	Before and after a series of four takeoffs and landings dragging the cone
Altitude	29,000 feet 12,000 feet 8,000 feet
Variations within one cone system	Four cone systems tested two to three times
Variations between identical cone systems	Two identical systems of one type Three identical systems of a second type

To conserve flight time, each cone was compared with a single test pitot-static tube (reference). To assure repeatability the installation of the pitot-static tube was not changed throughout the test series. This technique of using a reference system within the test airplane promised to save 80 percent of the flight time that would have been required to calibrate each cone by a ground radar or phototheodolite method.

Differential pressure gages were connected to the static lines from the pitot-static tube and the trailing cone systems. Calibrated test altimeters were also connected to each of the static lines. Calibrated airspeed and mach indicators were connected to the lines from the reference pitot-static tube. Figure 1 depicts the connections schematically.

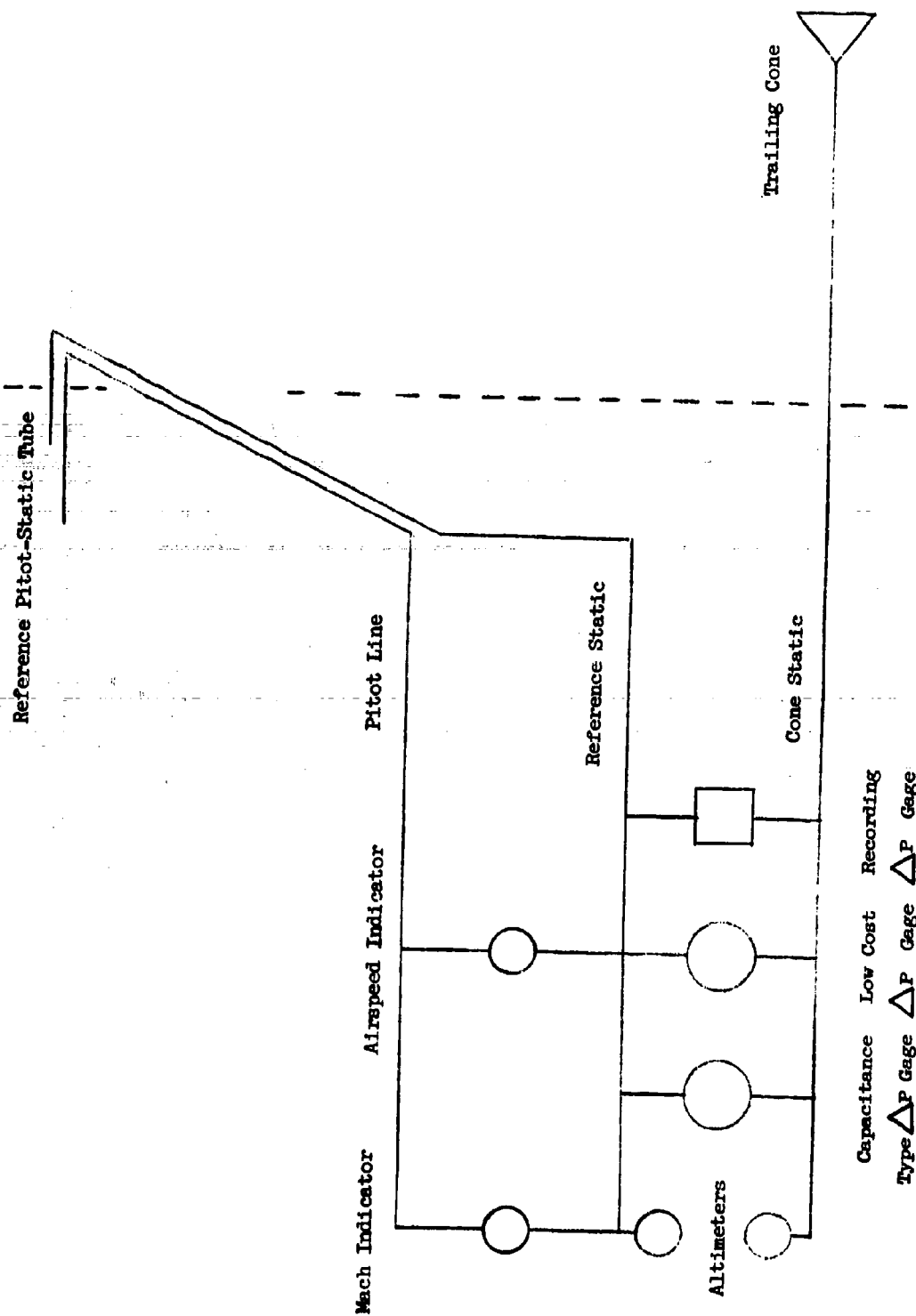


FIG. 1 SCHEMATIC DRAWING OF TEST PITOT-STATIC SYSTEM

System continuity checks were performed before all and after most tests. All such checks were conducted by simultaneously evacuating both static lines and pitot lines through their operational ports. In this fashion there were no unchecked connections when the check apparatus was removed. During the continuity checks the system's pressure was reduced to that equivalent to 25,000 feet. Due to the uncertainty of the effects of any leak, no readable leak was permitted over a period of one minute (less than five feet per minute).

The trailing cone assemblies were installed on a reel. Use of the reel permitted inspection of cone assemblies after flight without any damage during dragging on landing subsequent to data taking.

INDIRECT RESULTS

In the course of conducting this program, a number of different sensors and techniques were investigated.

If one is restricted to using absolute sensors, such as altimeters for measuring the difference between two pressures, it appears that the instrument error may be partially cancelled out by switching the sensor from one pressure to the other. Altimeters were used to investigate such a switching technique. At differential pressures of 0.1 inch of mercury, switching two altimeters from one static line to the other created a pressure increase in the lower pressure line at the instrument equivalent to 50 feet of altitude at 29,000 feet. After the pressure increase, the pressure gradually returned to its original value asymptotically. The time constant of this return was long enough (2 minutes) to make this switching technique unadvisable. The valves necessary for the switching were removed after this discovery.

Four different techniques were used for measuring the differential pressure between the cone line and pitot-static tube. Figure 2 shows relative results from each method. The different techniques along with the scatter obtained during a typical test for each of the techniques is as follows:

Recording high accuracy differential pressure gage	.30% $\Delta P/qc$
Capacitance type differential pressure gage	.30% $\Delta P/qc$
Low cost differential pressure gage	.22% $\Delta P/qc$
Altimeters	.50% $\Delta P/qc$

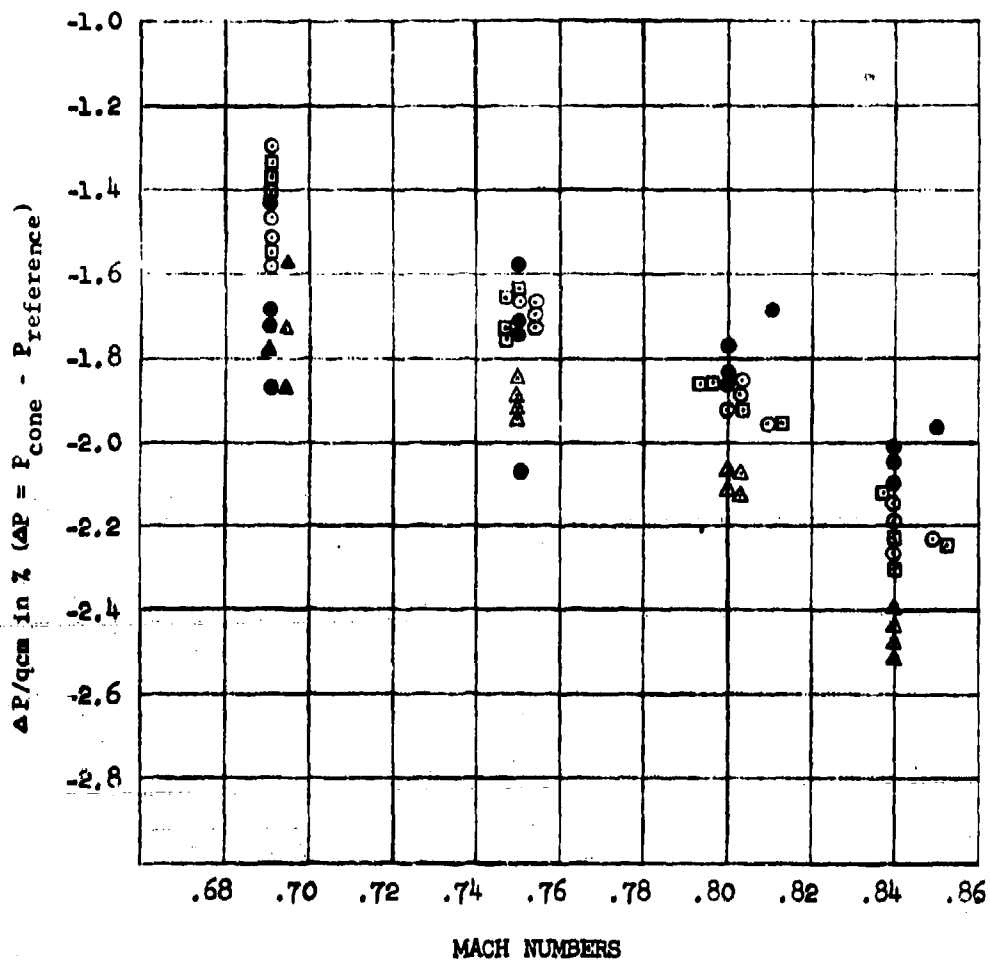


FIGURE 2. COMPARISON OF DATA MEASURED BY DIFFERENT SENSORS

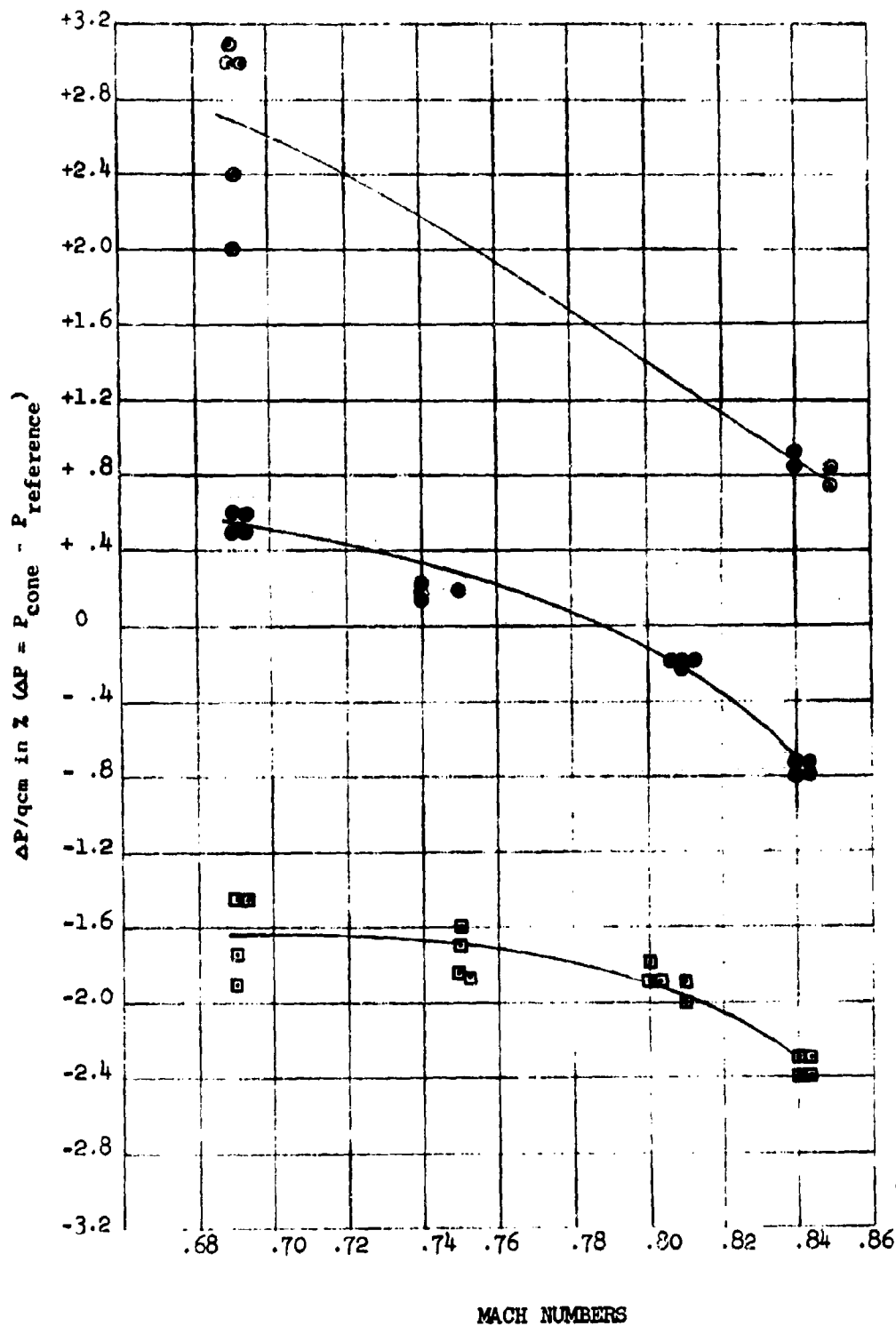
Suspicion was focused on the ground continuity check techniques when a leak appeared to be a possible cause of an extreme error in flight. Although no leak was found before the flight, was it possible that the cone system could leak during the flight? The practice of placing flight tension loads on the cone assembly during continuity checks was initiated. This was accomplished with a winch and a device for measuring the tension. 150-pound loading was used after two cone lines broke at 200-pound loading.

Leaks were discovered with the cone system under tension that were not revealed without the tension. These leaks were found at the aft seal of the plastic line, at the seals between the plastic line and the metal static port tube, and in the reel assembly. A commercial sealant corrected the leaks in the line seals. Replacing the O-Ring seals in the reel assembly eliminated the leaks there. No leaks were found in the plastic tubing itself and no pinholes were observed.

Considerable difficulty was experienced in obtaining reliable calibrations of the test instrumentation. Eventually, four different standards laboratories were utilized. Some of the variations in calibrations encountered can be attributed to the instrumentation itself. However, other variations appeared to be in the calibrating technique. For instance, in calibrating one differential pressure gage, one laboratory's results varied from day to day while the same instrument in another laboratory gave consistent readings. The calibrating equipment in each laboratory had about the same sensitivity. Still another laboratory attempted to calibrate the device against two mercurial barometers set up to read the absolute pressure on each side of the differential pressure gage. This technique produced the greatest variations in performance, in the order of .010 inch of mercury greater than the performance variations indicated by the laboratory giving consistent results. The consistent results were obtained by using a large bore dual cistern mercury manometer arranged to measure differential pressure directly. The calibration of the altimeters was also subject to considerable variations. Application of up-to-date barometer technology could have reduced these variations considerably (Reference 3). Unfortunately, a laboratory in this category was not accessible during the early part of this test series.

DIRECT RESULTS

Figures 3 through 15 present the findings on each of the variables investigated. Each figure shows the pressure difference between the trailing cone sensed pressure and the reference static pressure. The negative differences are caused by the relatively large pressure errors in the reference static system. On some of the figures, a probable calibration curve (corrections) for the pitot-static tube is also displayed. As some uncertainty exists in this calibration curve on the reference pitot-static tube, the true results are limited to the differences in performance of various trailing cone systems. If the depicted pitot-static tube curve has zero error the absolute error of the trailing cone systems is the depicted curve for a particular trailing cone minus the pitot-static tube curve.



The cone and test systems were successfully leak tested before Tests 4 and 9, and after Test 9, without tension on the cone line

FIGURE 3. REPEATABILITY - ONE CONE SYSTEM INSTALLED AND FLIGHT TESTED TWO DIFFERENT TIMES

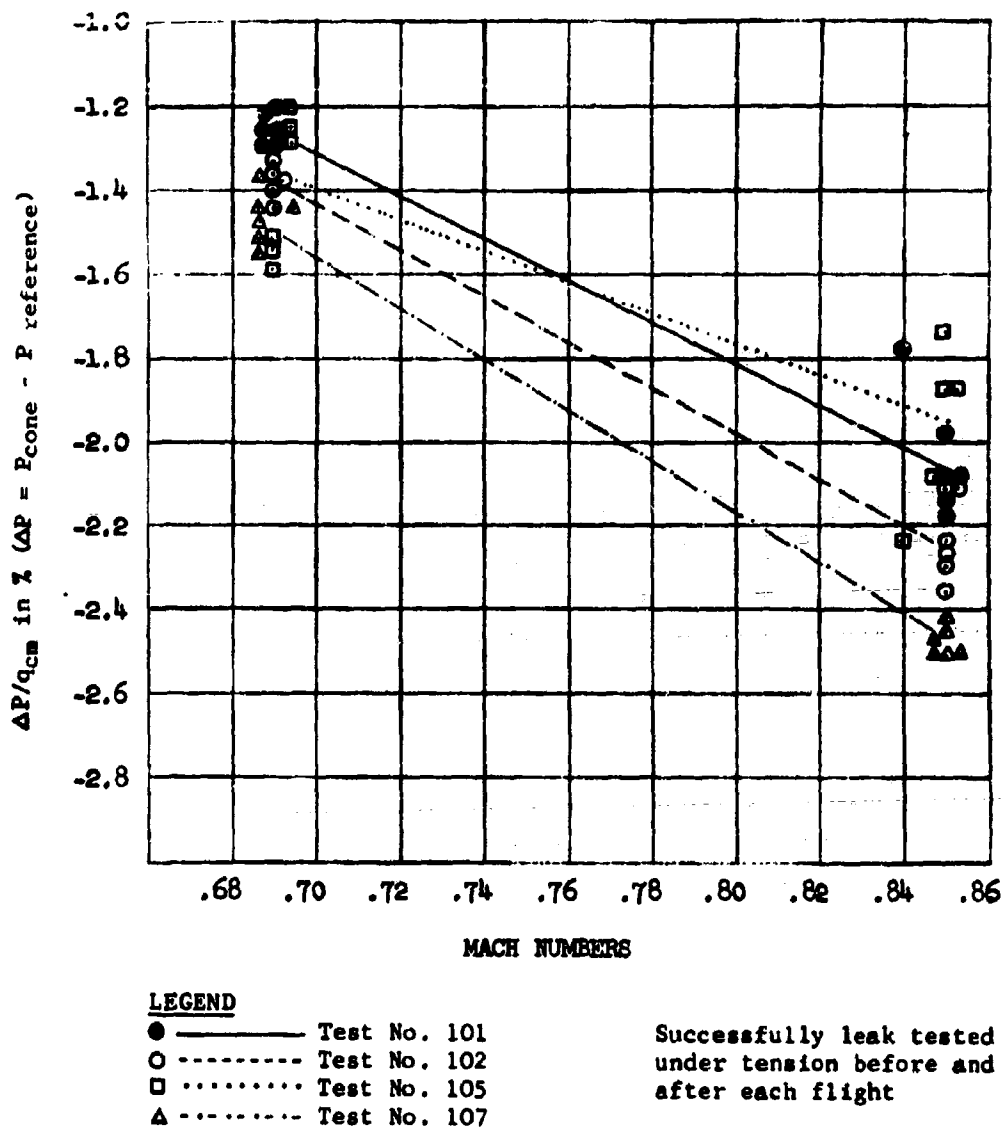


FIGURE 4. REPEATABILITY - ONE CONE SYSTEM INSTALLED AND FLOWN FOUR DIFFERENT TIMES

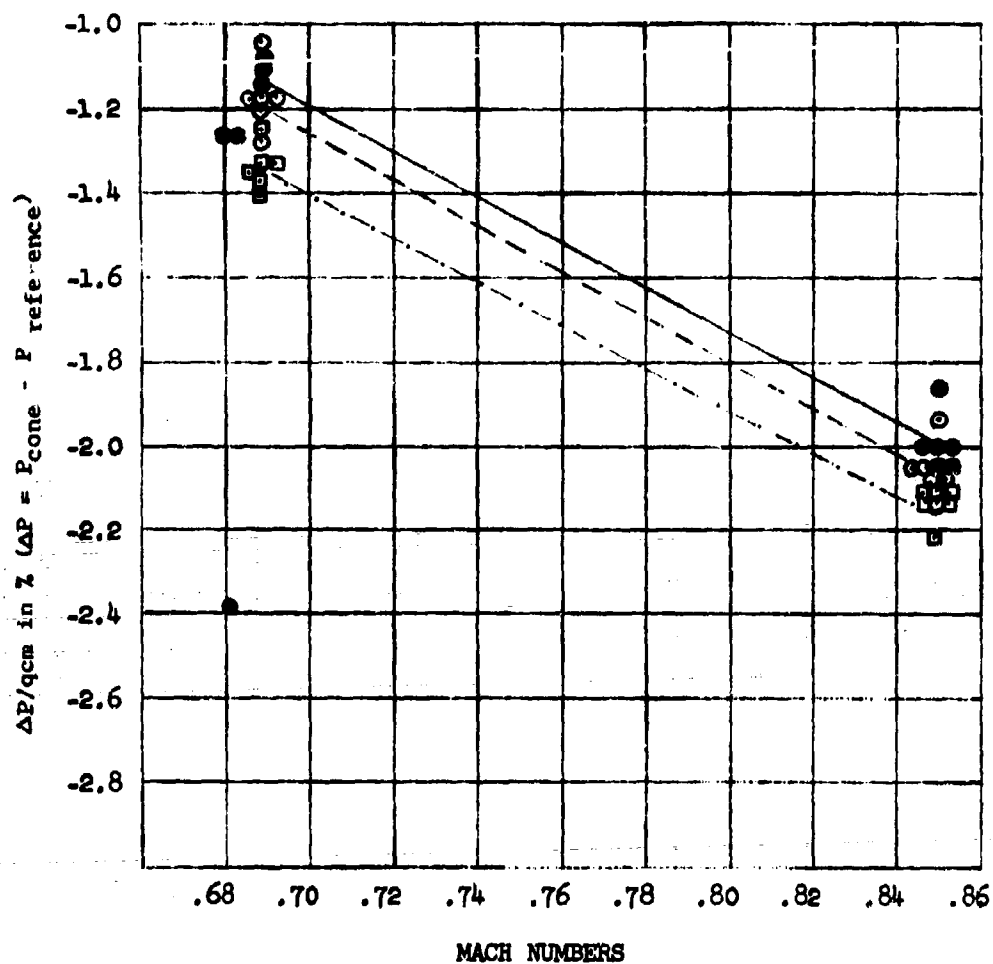


FIGURE 5. REPEATABILITY - ONE CONE SYSTEM INSTALLED AND FLOWN THREE DIFFERENT TIMES

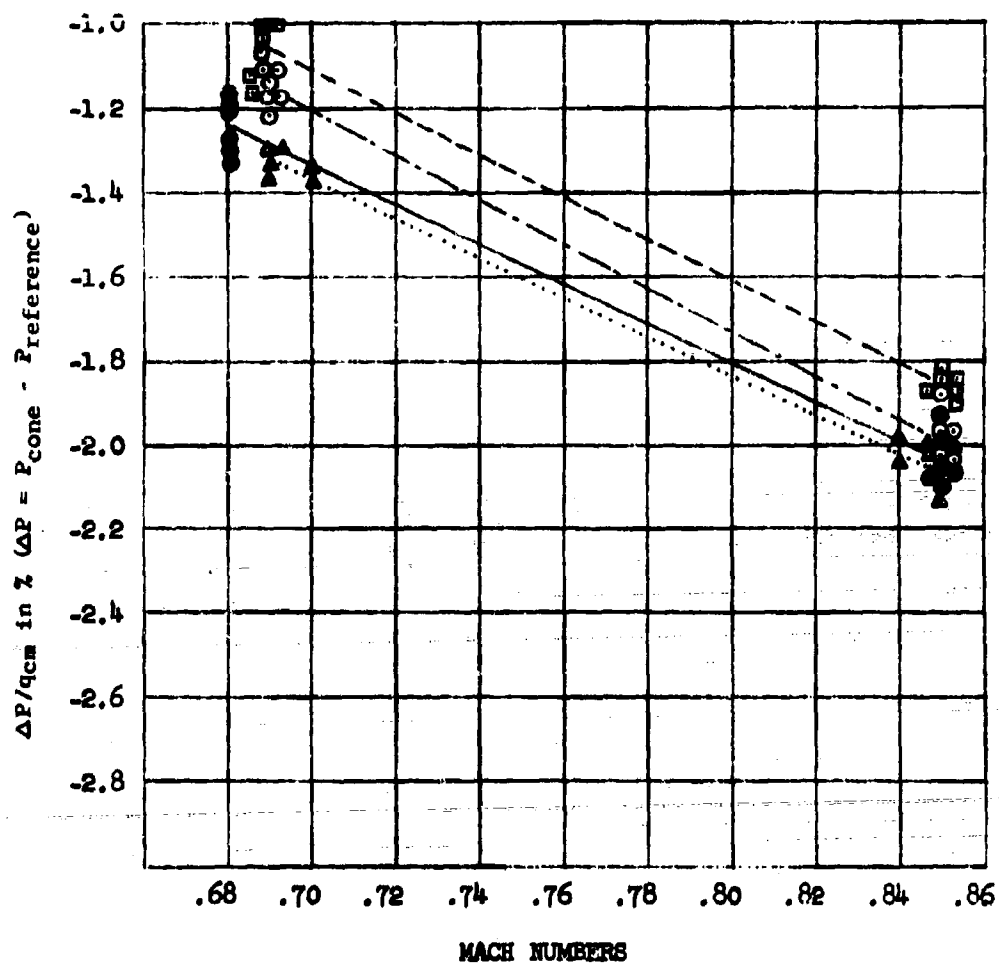
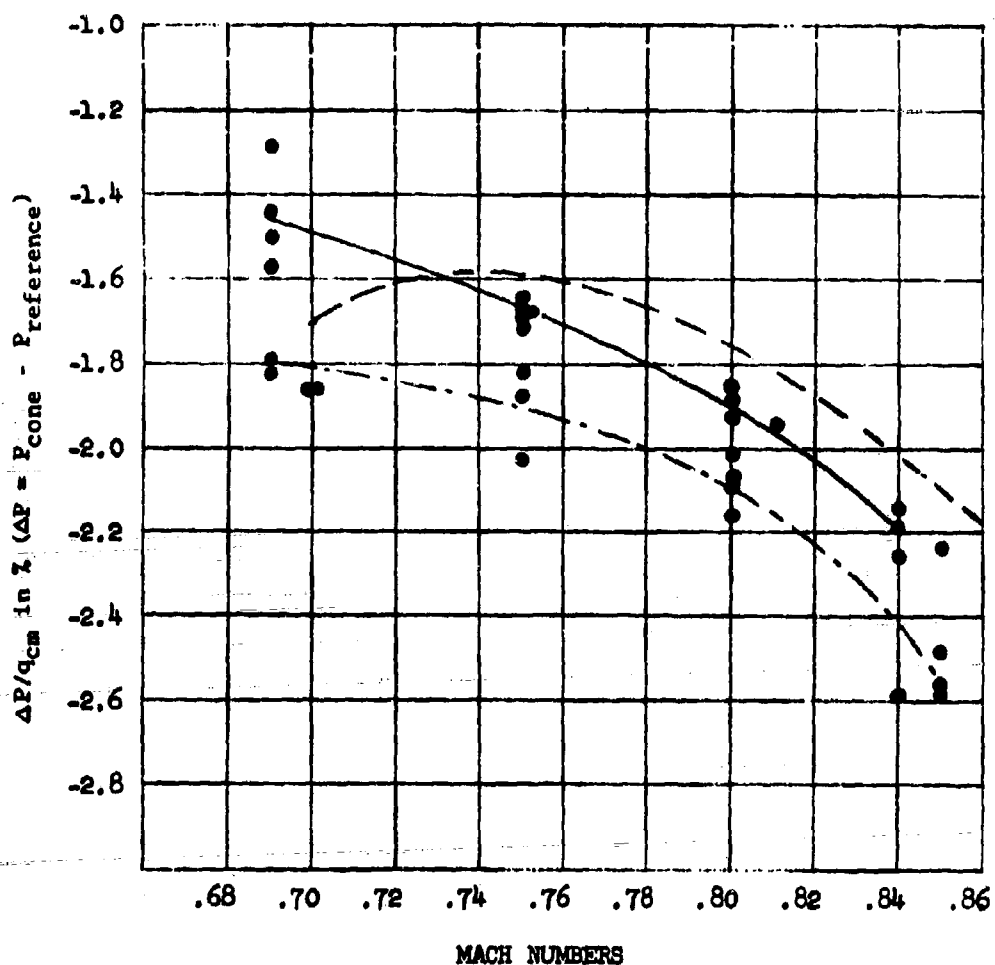


FIGURE 6. REPEATABILITY - ONE CONE SYSTEM INSTALLED AND FLOWN FOUR TIMES

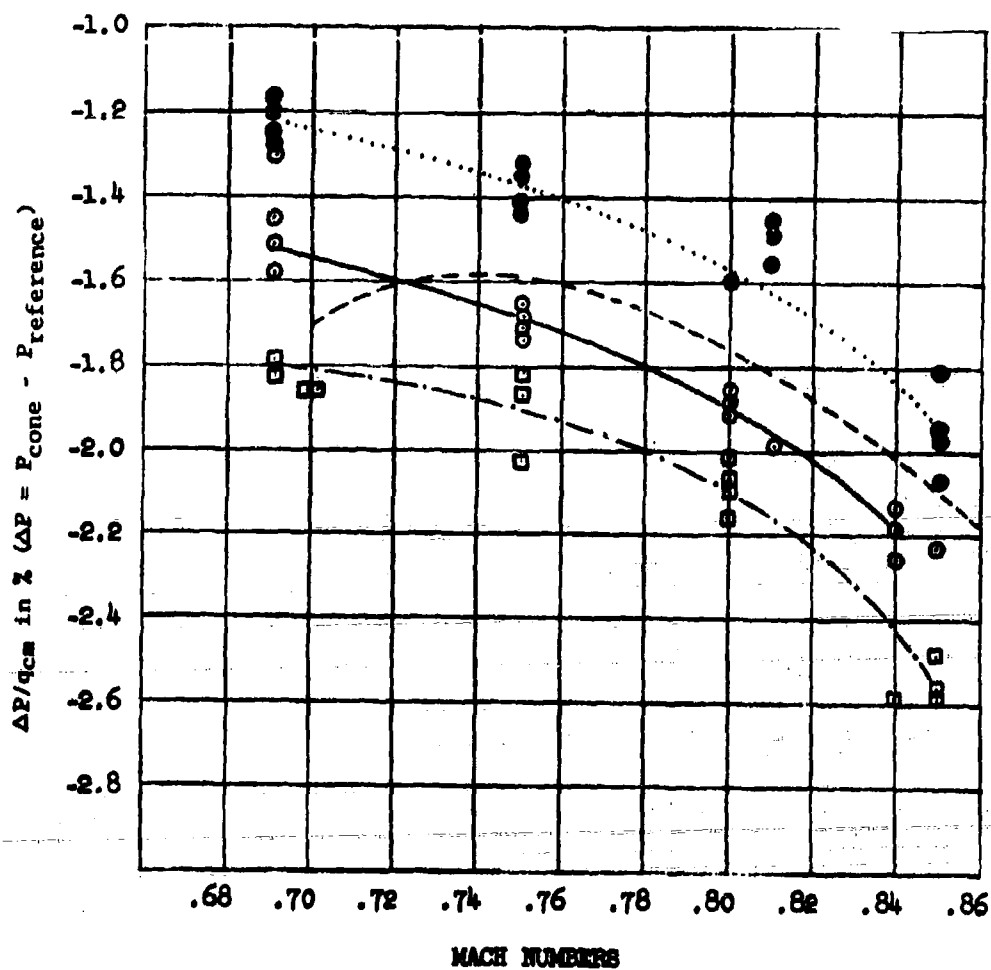


LEGEND

- — Test No. 7
- - - - Test No. 8
- - - Probable Pitot-Static Tube Calibration

These cone systems were successfully leak tested before Tests No. 7 and 8 and after Test No. 8 without tension on the systems. Both cone systems had 13 inch diameter drag cones and .252 inch diameter metal static tubes.

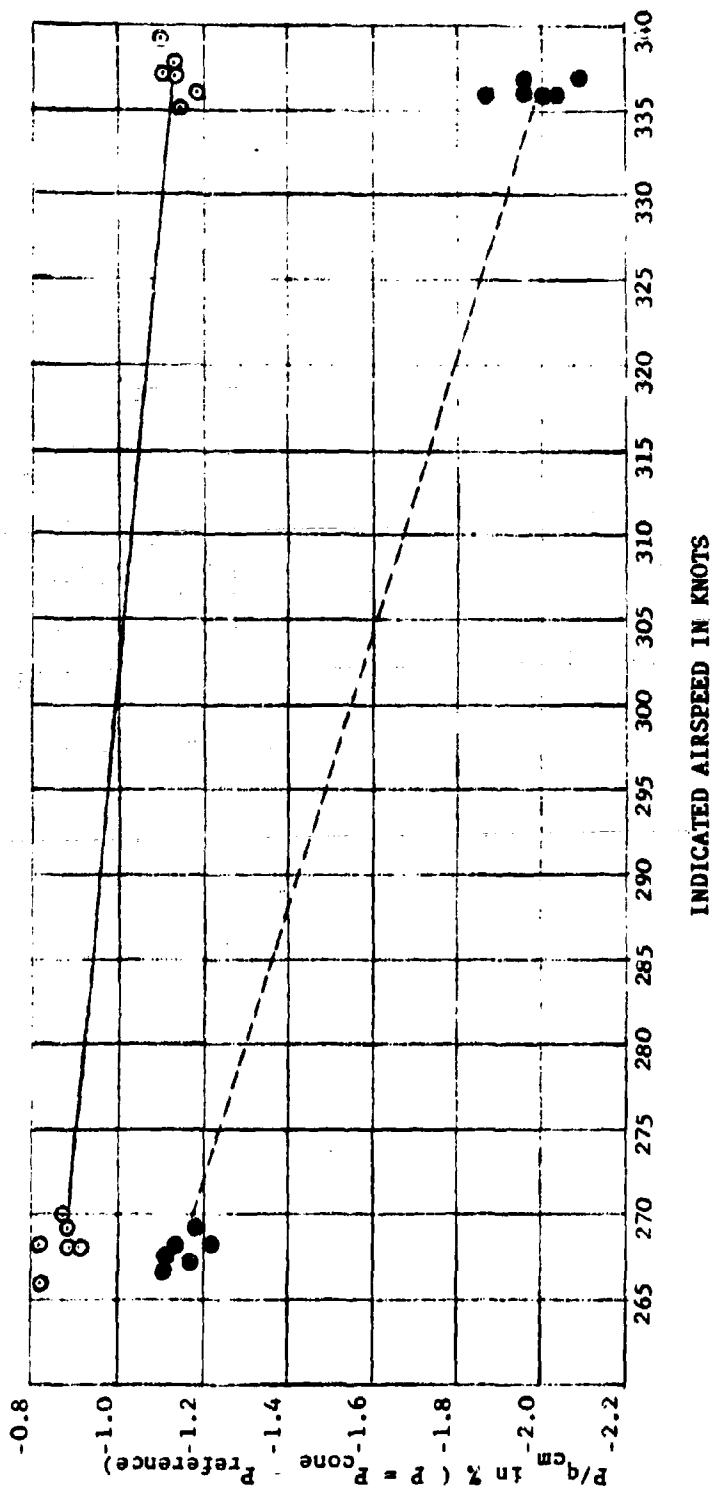
FIGURE 7. REPEATABILITY BETWEEN TWO IDENTICAL CONE SYSTEMS



LEGEND

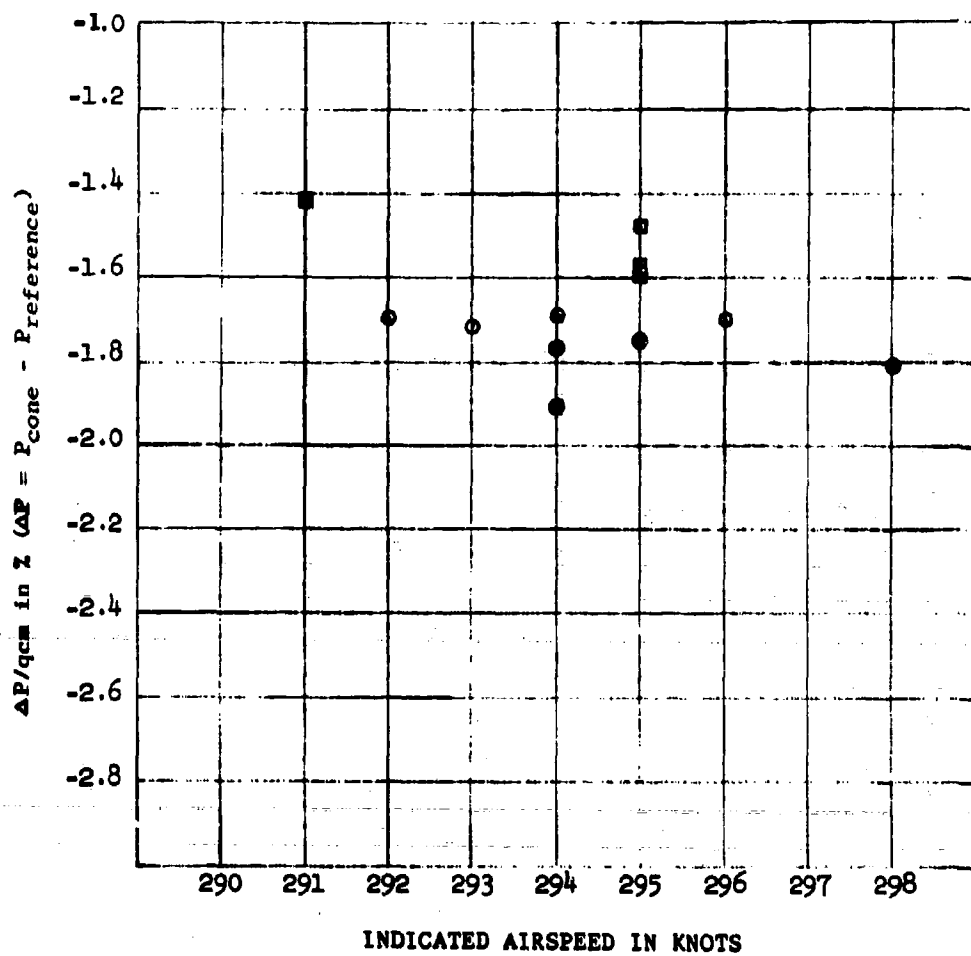
- Test No. 6. Double Size Orifices
(.036 in diameter)
- ——— Test No. 7. Standard Size Orifices
(.018 in Diameter)
- Probable Pitot-Static Tube Calibration
- - · - · - Test No. 8. Standard Size Orifices

FIGURE 8. EFFECT OF CHANGING STATIC ORIFICE SIZE



LEGEND
 O = Test No. 106 @ 12,000 feet
 ● = Test No. 106 @ 29,000 feet

FIGURE 9. PERFORMANCE AT DIFFERENT ALTITUDES



LEGEND

- Before Dragging
- After Dragging on One Landing and One Takeoff
- After Dragging on Four Landings and Takeoffs

FIGURE 10. EFFECTS OF WEAR BY DRAGGING ALONG RUNWAY ON TAKEOFF AND LANDING

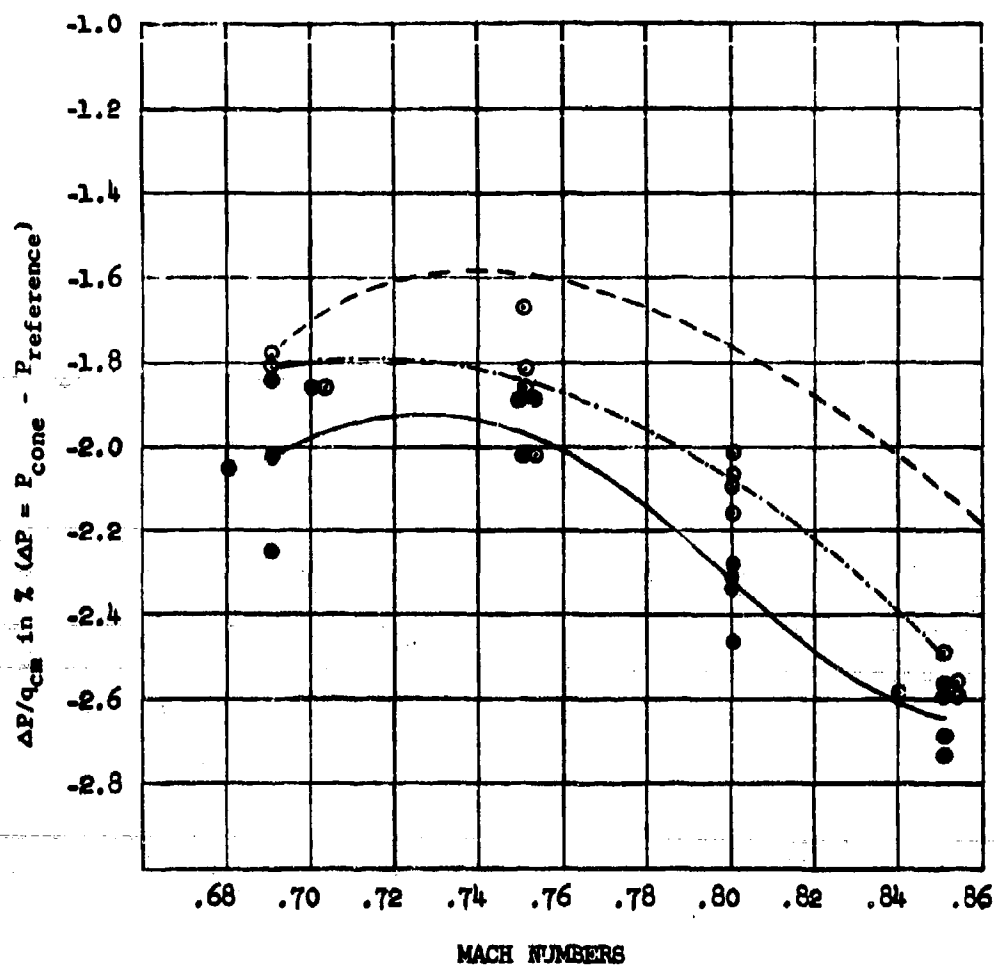


FIGURE 11. EFFECT OF VARYING DRAG CONE SIZE

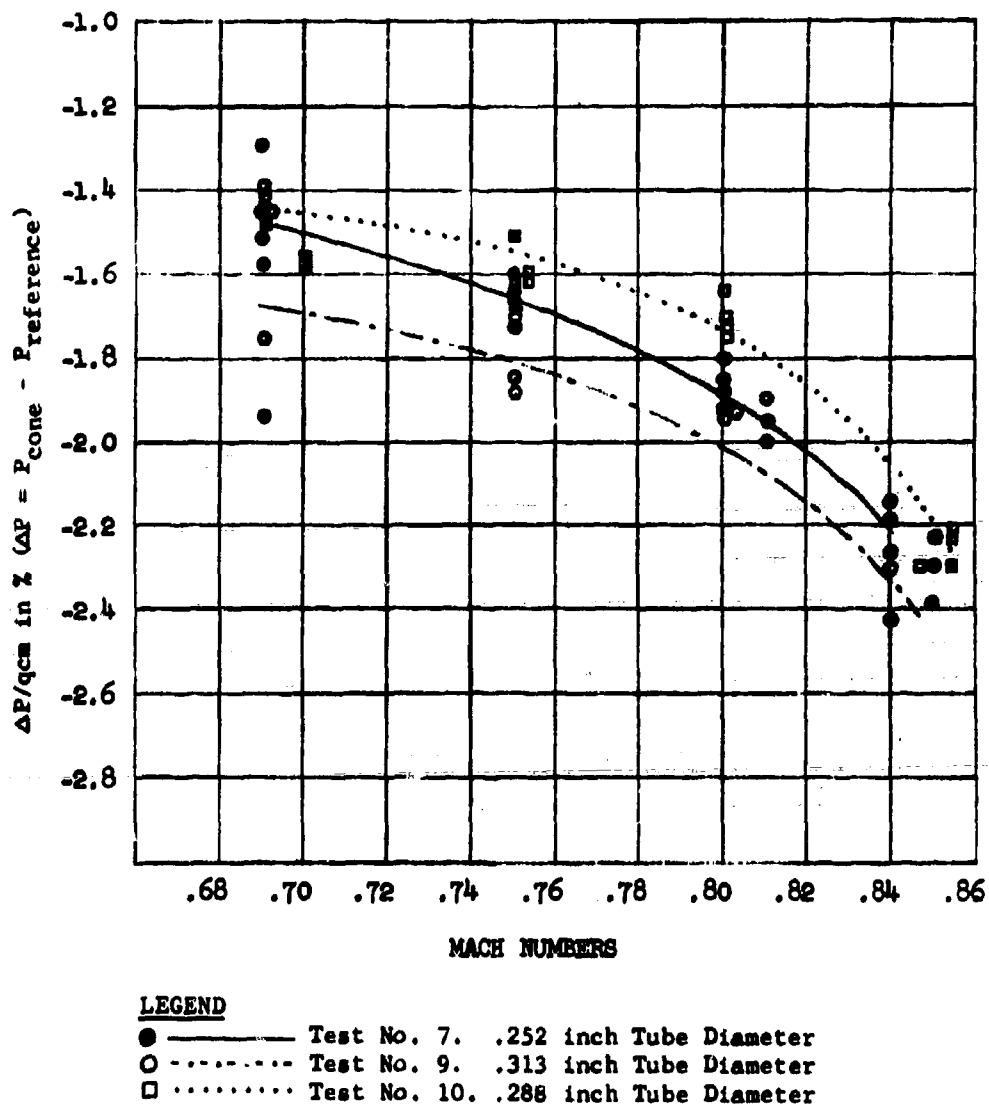
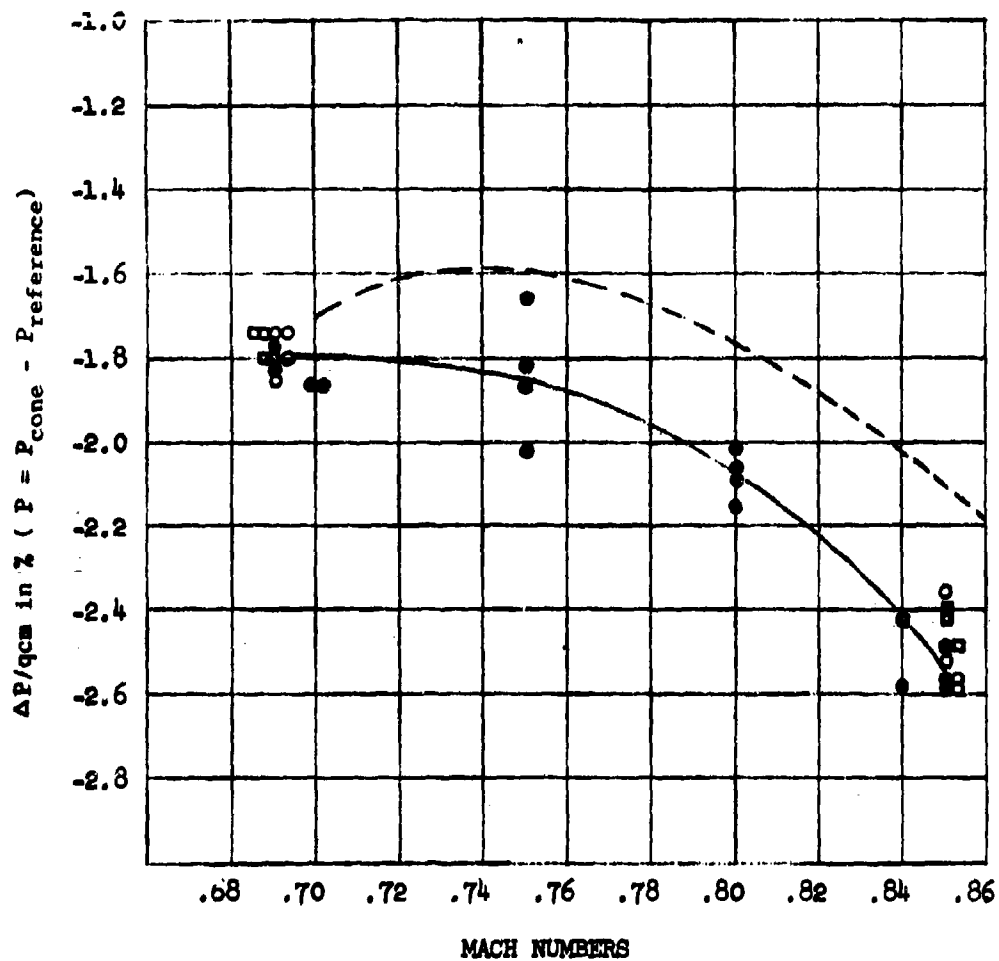


FIGURE 12. EFFECT OF VARYING METAL STATIC TUBE SIZE

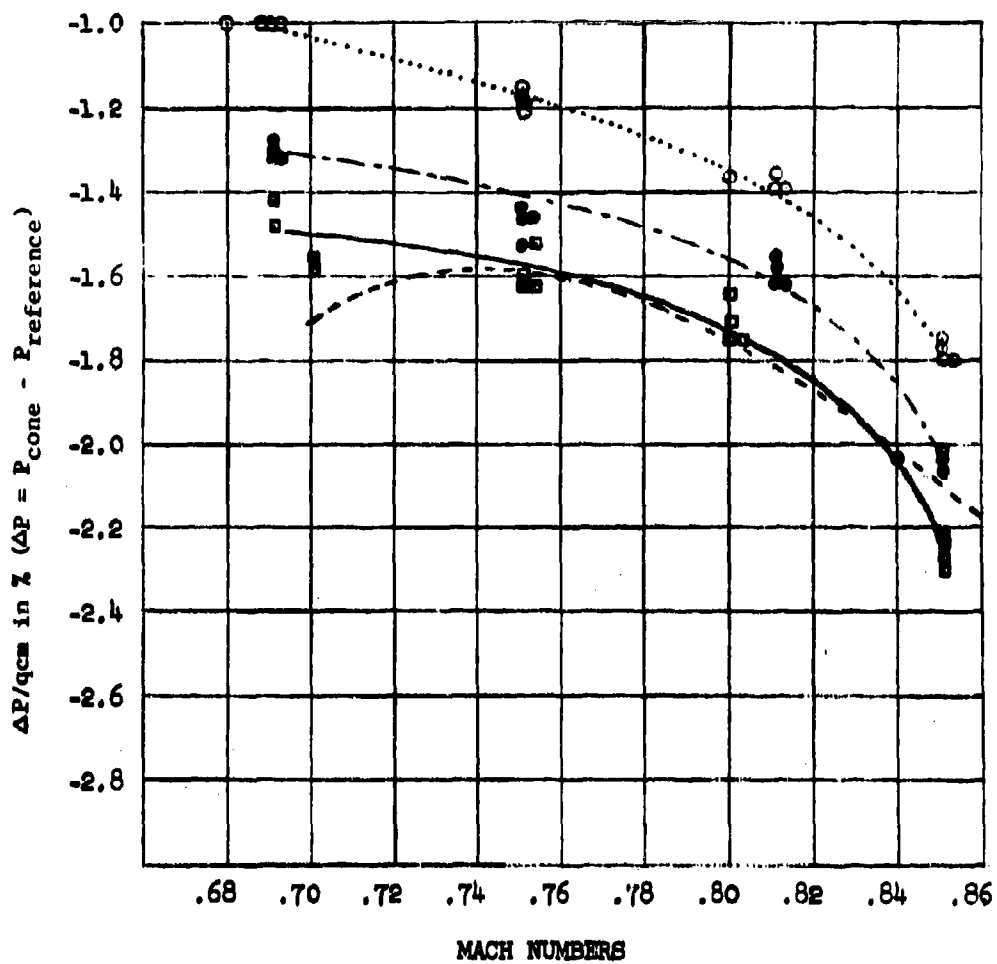


LEGEND

All data from Test No. 8

- ——— Trail Length = 100 feet
- ——— Trail Length = 75 feet
- ——— Trail Length = 50 feet

FIGURE 13. PERFORMANCE WITH DIFFERENT TRAIL LENGTHS



LEGEND

- - - - - - Test 1. Pan American Airlines Cone
- - - - - - Test 2. Pan American Airlines Cone
- - - - - - Test 10. NASA Cone
- - - - - Probable Pilot-Static Tube Calibration

FIGURE 14. ORIGINAL CONE SYSTEMS

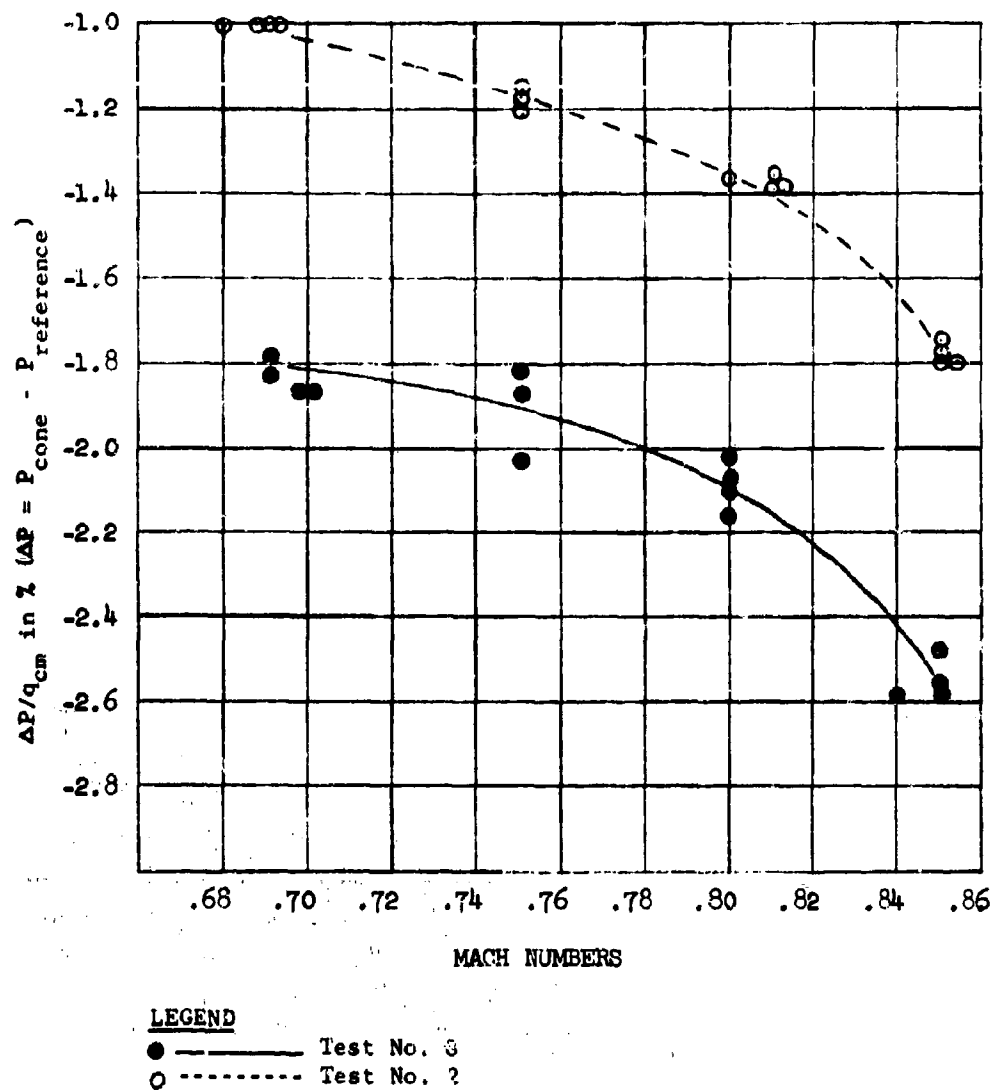


FIGURE 15. MAXIMUM DISPERSION NOT DIRECTLY ATTRIBUTABLE TO SYSTEM LEAKS

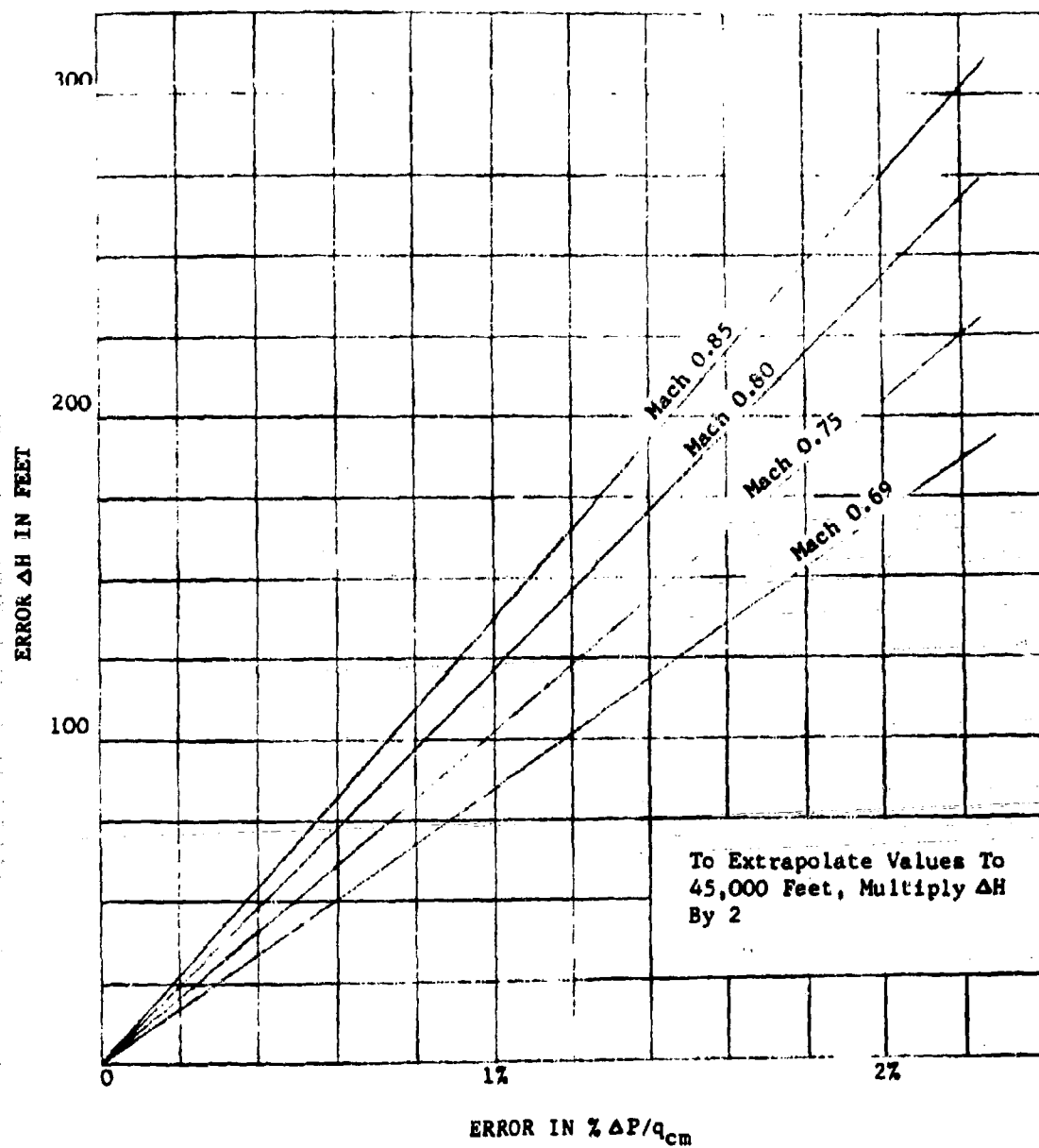


FIGURE 16. APPROXIMATE CONVERSION OF $\Delta P/q_{cm}$ INTO ΔH AT 29,000 FEET

CONCLUSIONS

1. The largest single variation in cone system performance was within the same cone during different tests (Figure 3). As this was before the application of improved continuity check procedures, the cause was probably a leak in the cone system installation.
2. With improved installation procedures the scatter of data from a given type of cone was held to 0.6% $\Delta P/qc$ at Mach 0.85 (Figures 4, 5, 6, and 7). Although this is acceptable at 29,000 feet, it can only be extrapolated to 35,000 feet before exceeding ± 50 feet.
3. Variations with static orifice size were significant. The changes in performance observed are equivalent to between 40 and 80 feet at 29,000 feet or between 80 and 135 feet at 45,000 feet (Figure 8).
4. Wear caused by dragging trailing assemblies during takeoff and landing may become significant after a number of such operations. In these tests (Figure 10), four takeoffs and landings caused 0.3% $\Delta P/qc$ change in performance on one trailing cone. (Extrapolated to altitude, this is equivalent to about 60 feet at 45,000 feet.)
5. In these tests, performance changes caused by separately varying the altitude, length of trail, size of metal static tube, and size of drag cone were not significant.
6. The maximum difference in performance of two trailing cone systems observed which is not directly attributable to leaks in flight was 0.8% $\Delta P/qc$ at Mach 0.85 (Figure 15). This is equivalent to about 110 feet at 29,000 feet or (extrapolated) 220 feet at 45,000 feet.

ACKNOWLEDGEMENT

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